Astronomy 122

This Class (Lecture 28):

The Beginning is the End.

HW11 due Wednesday

Music: *Pets* – Porno for Pyros

Final Exam

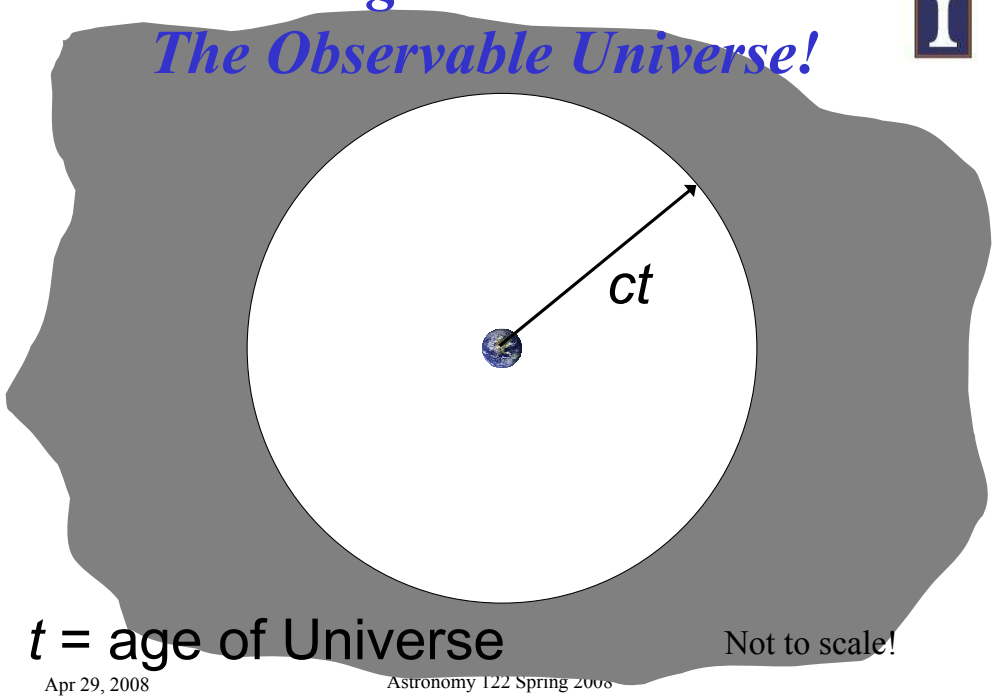
- In this classroom, May 6th from 1:30-4:30pm
- Multiple choice 70 questions.
- Can bring one sheet of notes
- Can bring a calculator if you want.
- Will be cumulative (80% new material)
  - 56 from the new and 14 from the old.
  - The old parts should be relevant to new discussions.
- Study guide is posted!

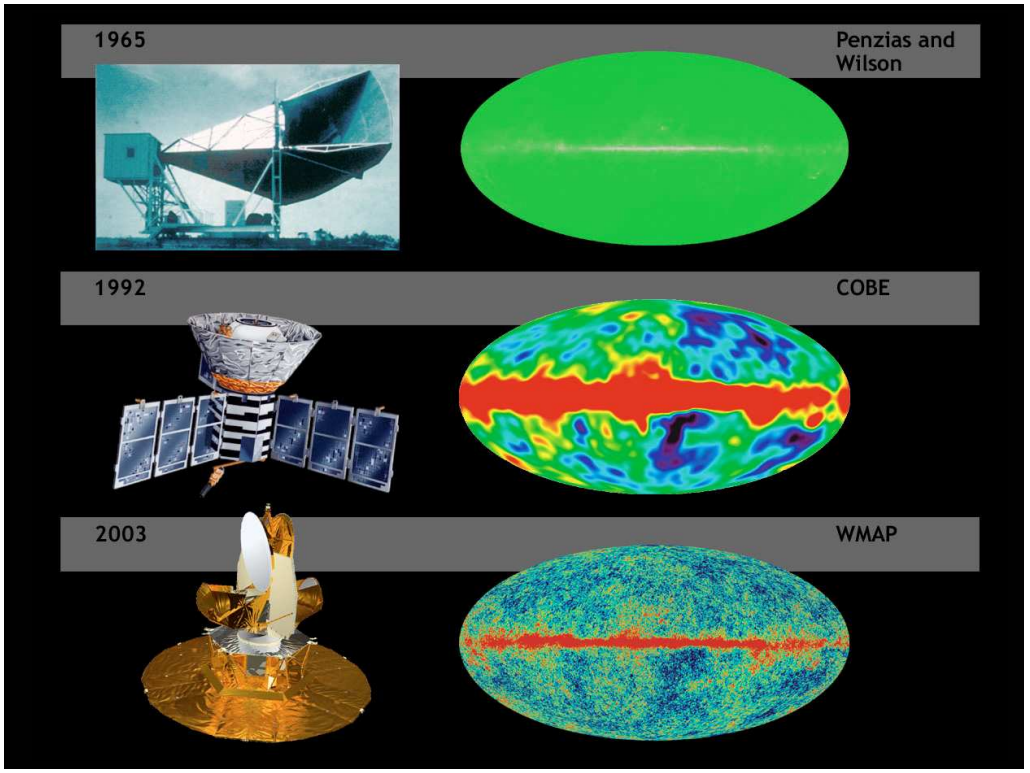
Wednesday Review

- Use the study guide before discussion class.
- Can you answer the questions posed?
  - Use the compass discuss board.
  - Ask direct questions in discussion.
- Discussion will also have Jeopardy review, directly based on Final Exam questions.

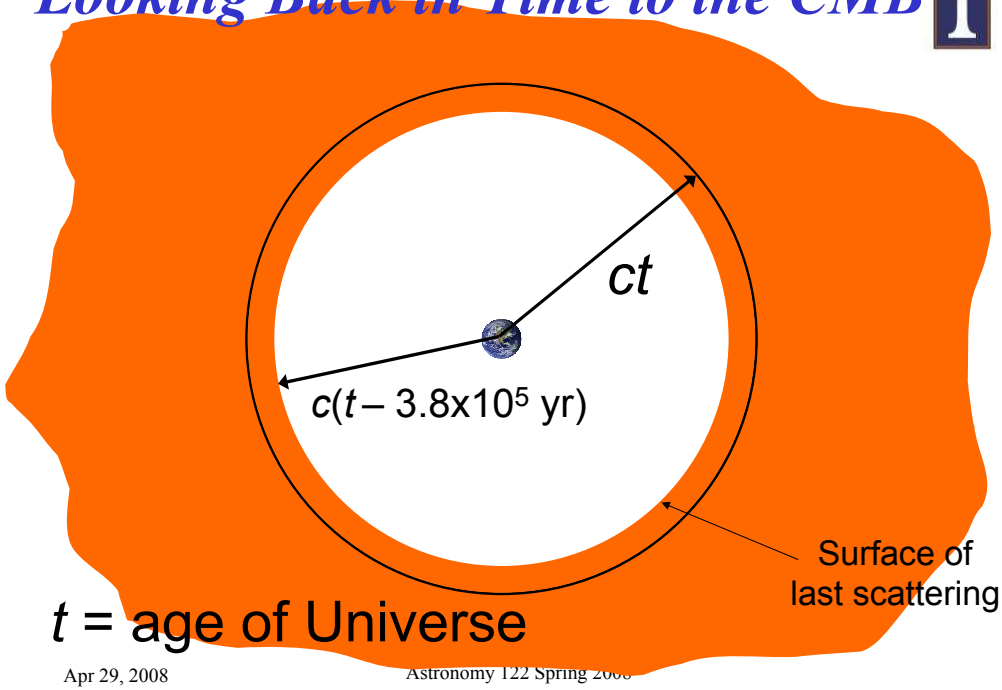
Outline

Looking Back in Time: The Observable Universe!



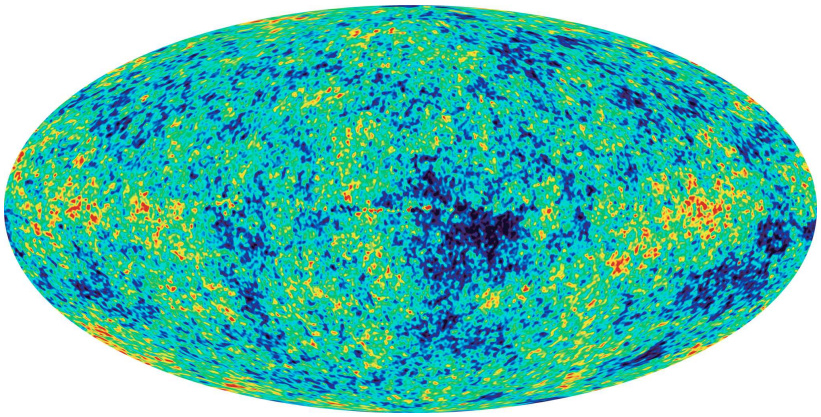


Looking Back in Time to the CMB

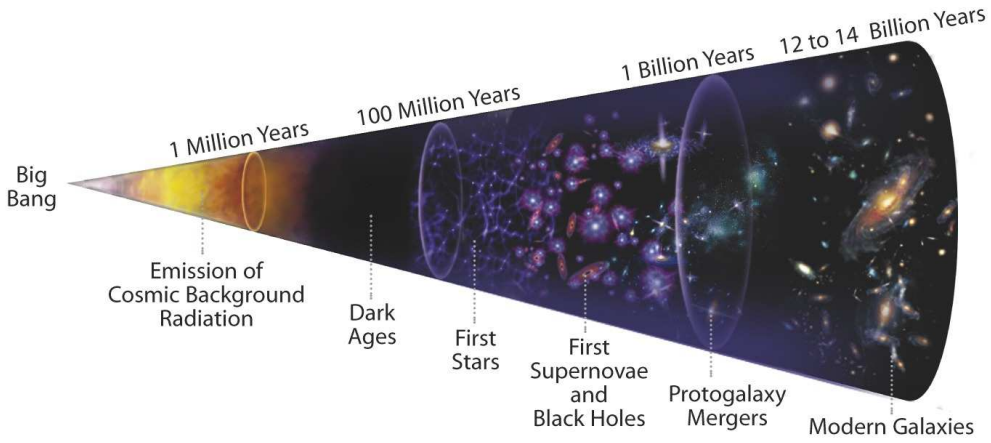


The Seeds of Galaxies

These small perturbations in temperature are the fluctuations (smaller than 1 in a 100,000) that caused the large scale structures we see today. This is what formed galaxies. All of this happened only 400,000 years after the Big Bang.

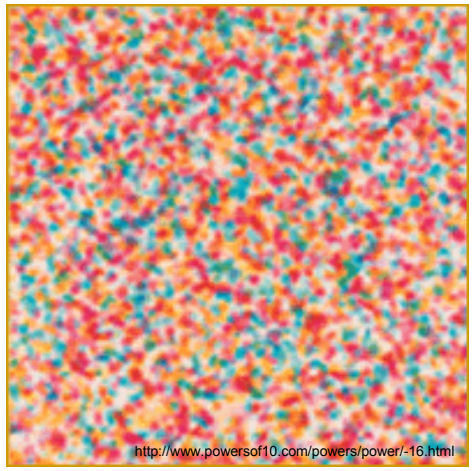


A Brief History of Time



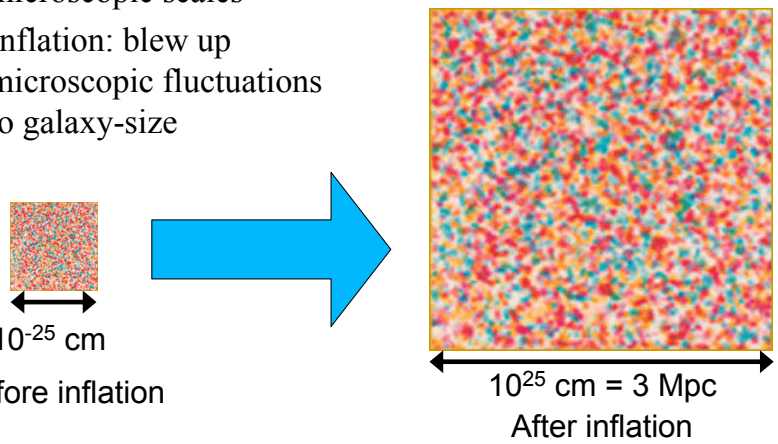
The GUT Era (until 10^{-35} sec)

- GUT = "Grand Unified Theory"
- Sea of free quarks (and anti-quarks) + photons + other basic particles
- Random fluctuations in density



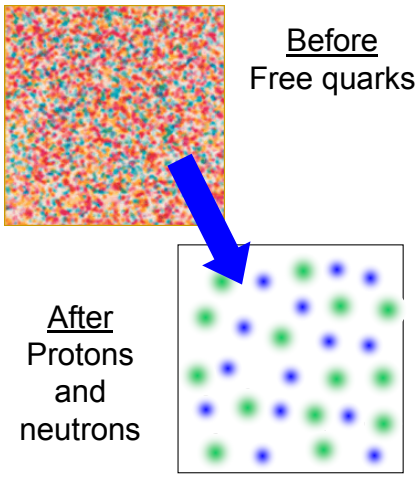
Origin of the CMB Fluctuations

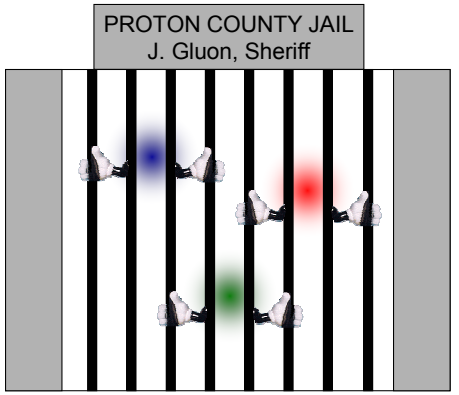
- Early Universe: a sea of particles & energy
- Density was constantly fluctuating on microscopic scales
- Inflation: blew up microscopic fluctuations to galaxy-size



Quark Confinement

- 10^{-6} seconds: free quarks condensed into protons and neutrons

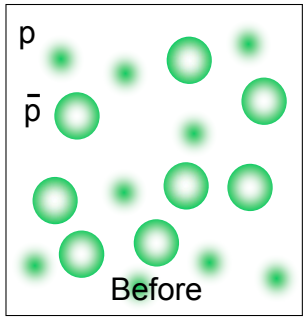


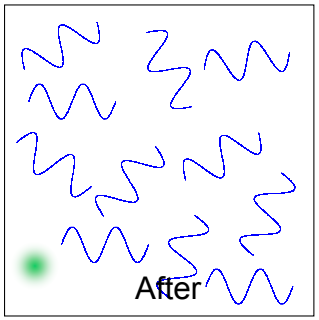


10^{31} years to life
Little chance of parole

Annihilation of the Anti-matter

- 10^{-4} seconds:
  - Temperature dropped below the level at which photons have enough energy to create proton-anti-proton pairs
  - Remaining pairs annihilated → radiation
  - 1 proton in 10^9 had no partner! That's us.
  - The first hydrogen atoms (ionized but there)





The Early Universe and Antimatter

Strong evidence says:
The early universe had both matter and antimatter, but
- For every 1,000,000,000 antimatter particles,
- There were 1,000,000,001 matter particles

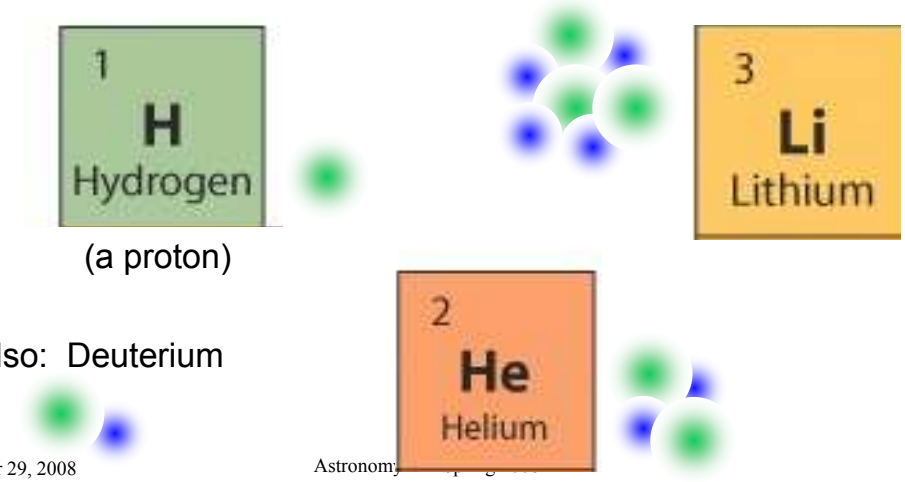
Then annihilation happened, only the matter excess remained.

How did the matter excess get there?
Most likely guess:
- The Universe began with equal amounts of matter & antimatter.
- But very high energy reactions slightly favored matter.
- Fermilab experiments: such reactions are possible!
- Stay tuned!

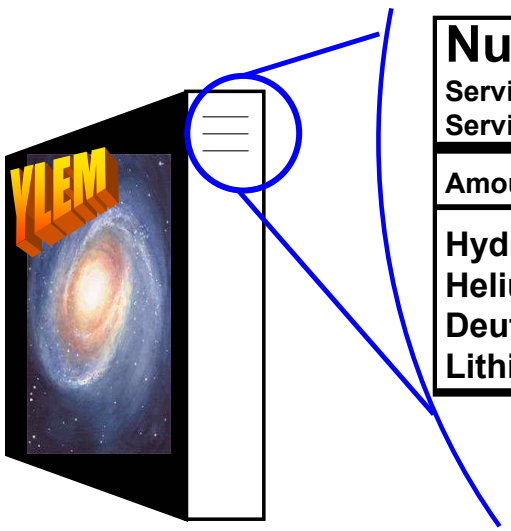
Example of inner space--outer space, particle--cosmology connection.

Big Bang Nucleosynthesis

When the Universe was 1 sec to 3 mins old, the temperature fell to 10^9 K and protons and neutrons can "shack-up" to form the first light elements.



End Result: Big Bang Correctly Predicts Abundances



Nutrition Facts

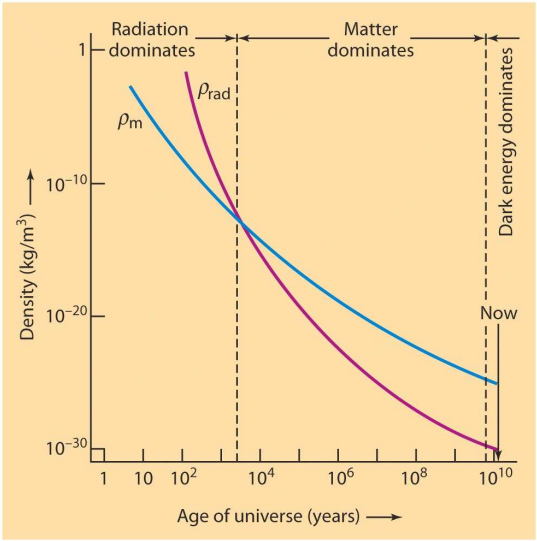
Serving Size 1 g
Servings Per Universe many many

Amount Per Serving

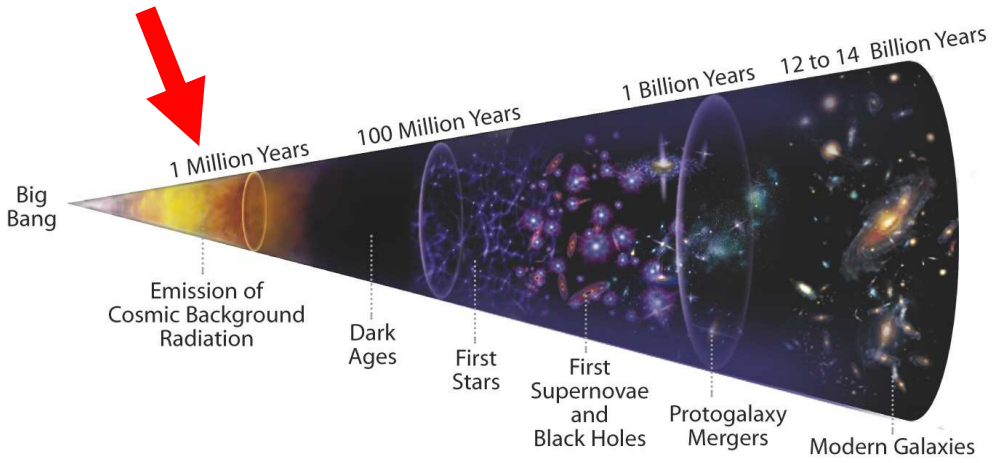
Hydrogen	**0.75 g**
Helium	**0.25 g**
Deuterium	**10^{-4} g**
Lithium, etc.	**10^{-10} g**

Radiation Domination

- In the early Universe, most of the energy was in radiation
- As the Universe expanded, photons were redshifted
  - Lost energy
- After 30,000 years, most of the energy of the Universe was in matter

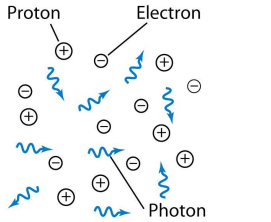


Origin of the CMB

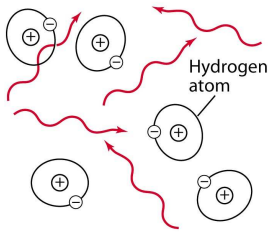


Era of Recombination

- In the early Universe, photons were energetic enough to keep atoms ionized
  - protons and electrons couldn't make neutral hydrogen atoms
- After 500,000 years, photons couldn't ionize hydrogen anymore
  - Expansion of space stretched photons' wavelengths
  - Not enough energy to ionize hydrogen
  - Universe became transparent to photons
- This radiation is the source of the Cosmic Microwave Background!



a Before recombination



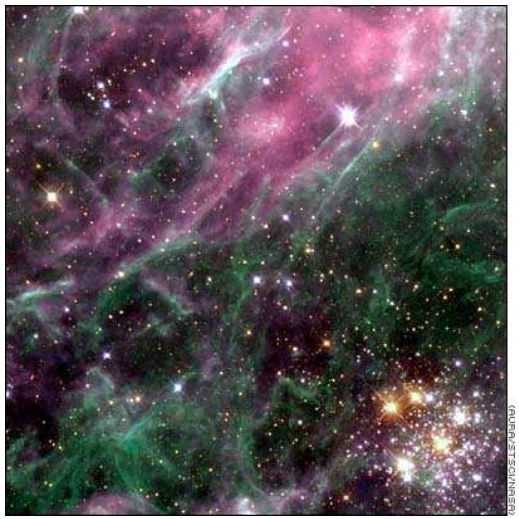
b After recombination

- After recombination came a period known as the Dark Ages
  - 500,000 to 100 million years
  - No light comes to us from this period
- Matter consists of warm clouds of hydrogen and helium
  - Too hot for star formation to occur
  - Gravity slowing drawing clouds together into bigger and bigger clumps

http://www.darkages.com/

The First Stars

- We think the first stars began to form after about 200 million years
- Proto-galactic clouds are slowly collapsing – no galaxies yet



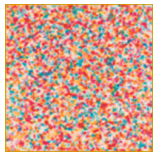
Question

What if our solar system formed with the first generation of stars? How would our solar system be different? Would the Earth exist as a habitable planet?

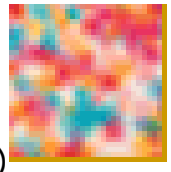
a) Very different.
b) It would be hotter.
c) About the same, really.

The Beginnings of Galaxies

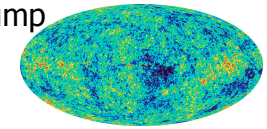
Quantum fluctuations during GUT era (before 10^{-35} s)



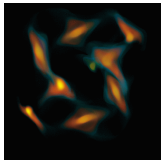
Inflation stretches fluctuations to galaxy size (before 10^{-32} s)



Before recombination, particles moving too fast to clump

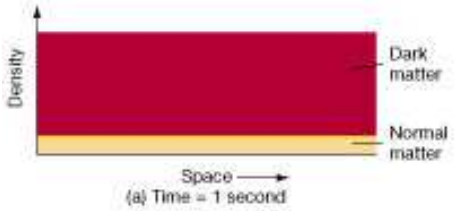


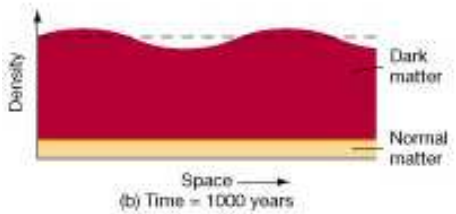
After recombination, gravity of denser regions draws particles together

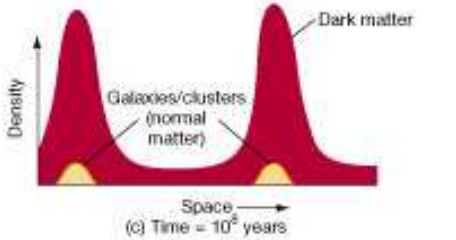


Fluctuations Were Good for Us

Gravity enhances the perturbations over time into galaxies.

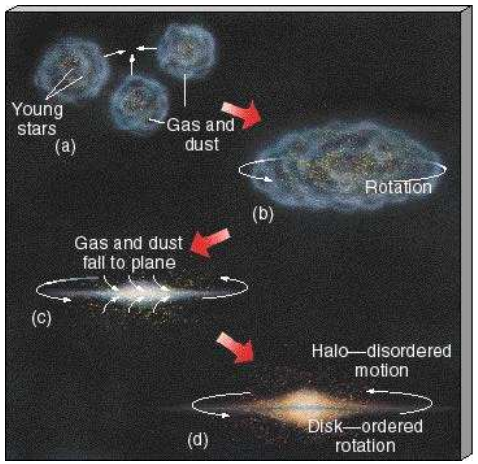


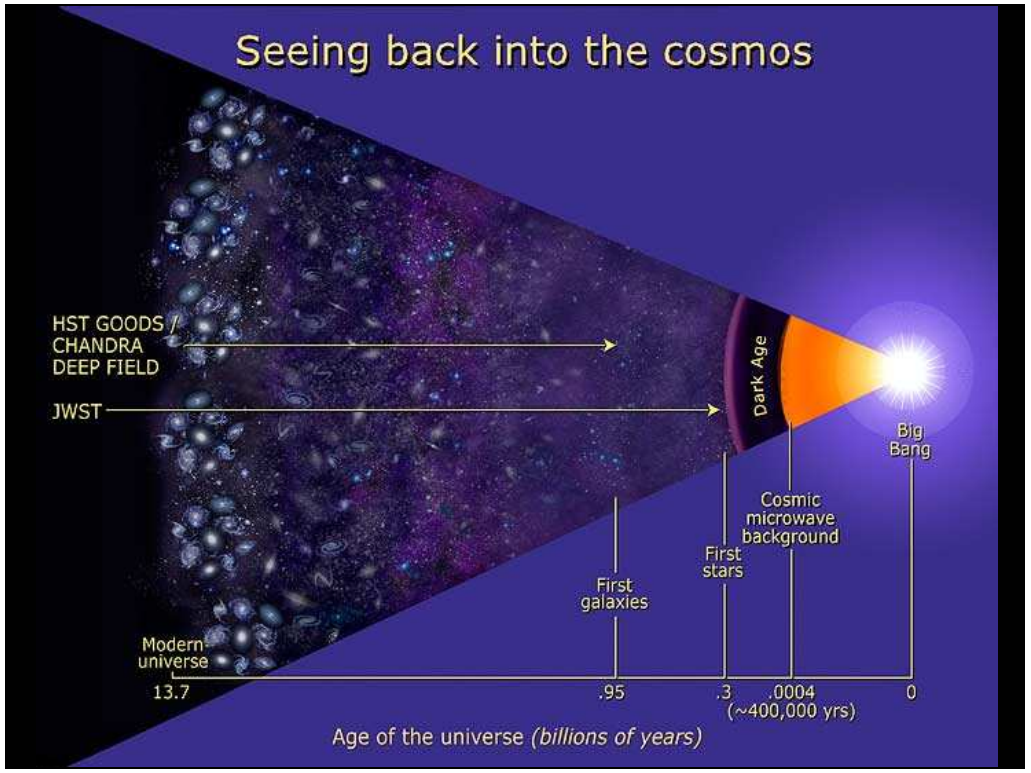




Galaxy Formation

- Regions of higher density became the seeds of galaxies, clusters, and superclusters
- Collapsed under their own gravity
- Well-fed supermassive black holes at galaxy centers became quasars



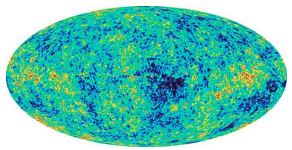


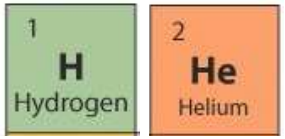
From the Home Office in Urbana, IL
Top 3 Reasons We Believe in the Big Bang

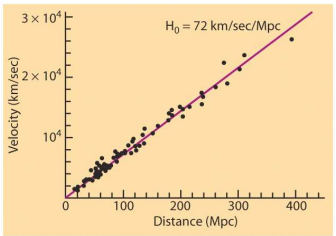
1. Cosmic Microwave Background
   - Big Bang working at about 500,000 yrs
   - Tiny fluctuations: "seeds" of galaxies
2. Big Bang Nucleosynthesis
   - H and (almost all) He come from the Big Bang
   - Big Bang working at 1 sec
3. The Hubble Law: $v=H_0 d$

   + Einstein's General Relativity

   = Expanding Universe with an age of 13.7 billion yrs







Question

The seeds of Galaxies were due to?

a) Large super structures in the early Universe.
b) Nuclear strong force fields.
c) Quantum fluctuations in quark density.
d) Gravitational instabilities in the fabric of space-time.
e) Unclear reasons.

What is the fate of the Universe?

Fire and Ice

Some say the world will end in fire,
Some say in ice.
From what I've tasted of desire
I hold with those who favor fire.
But if it had to perish twice,
I think I know enough of hate
To say that for destruction ice
Is also great
And would suffice.

-- Robert Frost

What is the Universe's Fate?

Today: Universe is expanding. What do you expect to happen next?

Competition: gravity vs inertia

Compare: Pop fly and rocket!

- Quantitative question
- Launch speed vs speed to escape Earth

or

?

What is the Universe's Fate?

For Universe it is still gravity vs speed.

- Gravity acts on mass of galaxies (pulling back)
- The speed is the speed of expansion

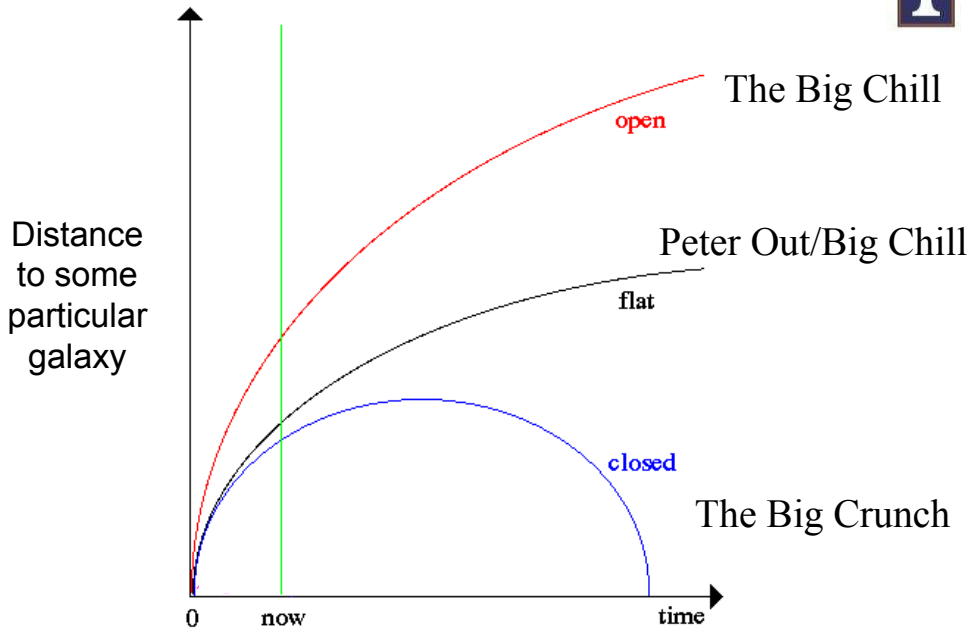
Both are observable!

or

Our fate is a **quantitative** question :

- **If our mass is small enough we expand forever.**
- **If our mass is large enough expansion halts, and we collapse.**

What kind of Universe do we live in?



Big Chill/Big Crunch

- **Less mass:**
  An open or flat Universe will end in a **Big Chill**:
  - Galaxies exhaust their gas supply
  - No more new stars
  - Old stars eventually die, leaving only dust and stellar corpses
- **More mass:**
  A closed Universe will end in a **Big Crunch**:
  - Expansion will stop, and the Universe will re-collapse
  - Ends as it began, incredibly hot and dense

Think-Pair-Share

What kind of a Universe would you want to live in?

a) Open
b) Closed
c) Flat

How Much Do We Weigh?

% of mass for closed Universe

22% Dark matter
Needed to explain:
galaxy rotation curves
clusters of galaxies

4.5% Ordinary matter
Made of protons, neutrons, and electrons

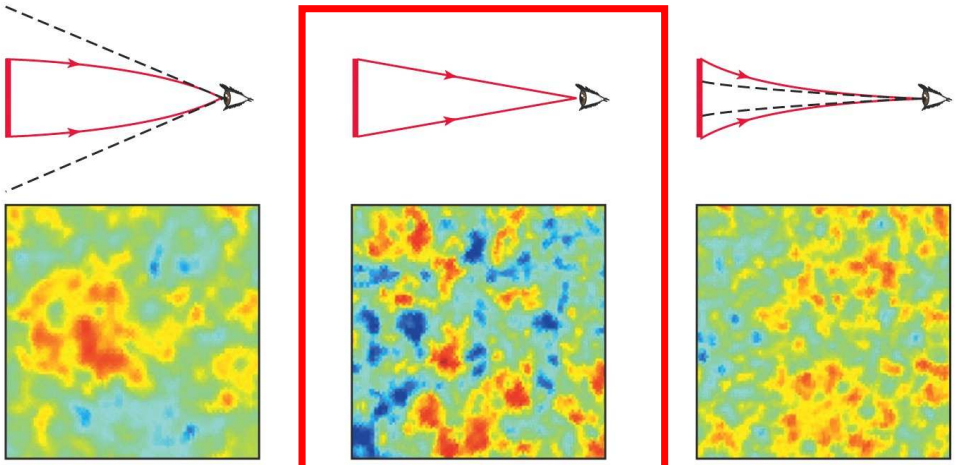
<1.5% Neutrinos

28% Total Not enough to close the Universe

So we live in an open Universe?

CMB Measurements

Universe is Flat!!!!



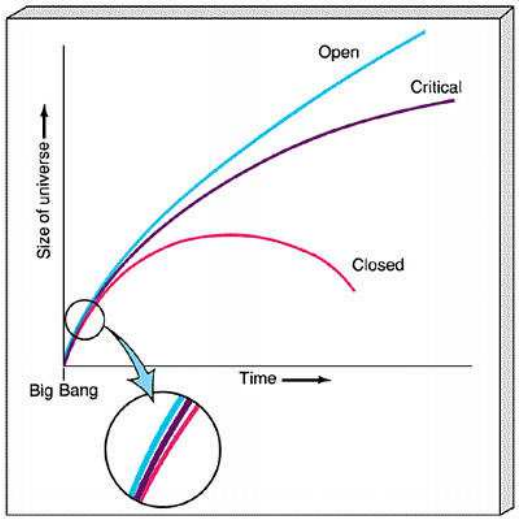
a If universe is closed, hot spots appear larger than actual size

b If universe is flat, hot spots appear actual size

c If universe is open, hot spots appear smaller than actual size

Why Is The Universe Flat?

- Flat universe stays flat
- Open or closed universes rapidly deviate from flatness
- Our Universe is very nearly flat ⇒ fine tuning?



http://blueox.uoregon.edu/~jimbrau/astr123/Notes/Chapter27.html

Peter Out/ Big Chill

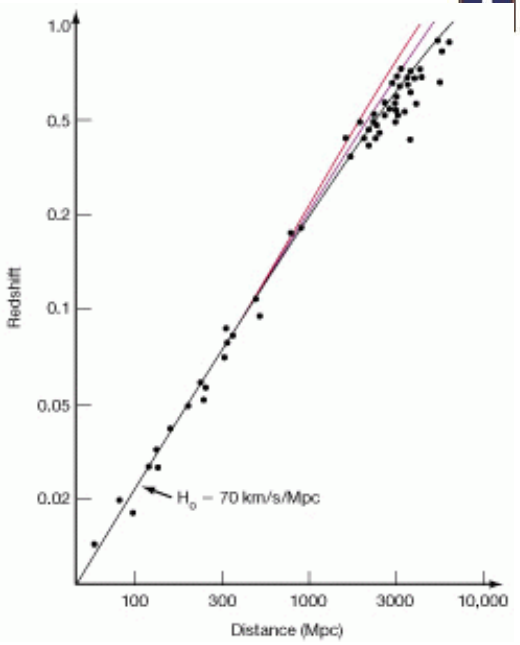
- The Universe will just barely expand forever, getting cooler and cooler.
- If all of the mass, dark+regular, isn't enough, **then what's up?**
- The fate of the Universe is really dependent on the amount of matter and energy in the Universe → $E = mc^2$

We must be missing some extra mass/energy?

The Accelerating Universe!!!

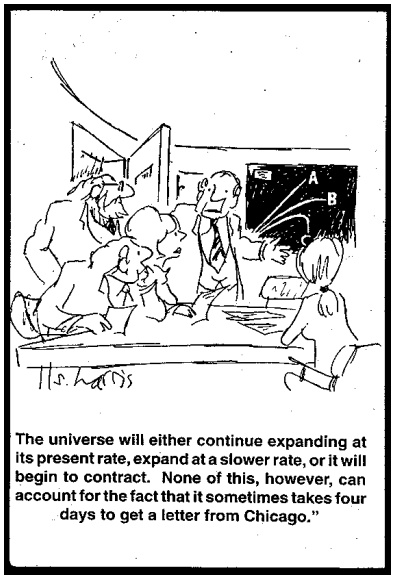
The universe is not slowing down at all. In fact, it's speeding up!!! We live in an accelerating universe!

It's as if there's another force pushing the universe apart – a Cosmological Constant!!!



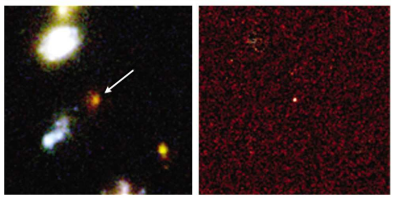
Dark Energy

- The matter census isn't enough to be flat and the expansion is accelerating!
- So, a new type of energy called ***dark energy*** must exists
  - Not related to dark matter
  - Acts as repulsive gravity
- Dark energy is actually *accelerating* the expansion of the Universe!

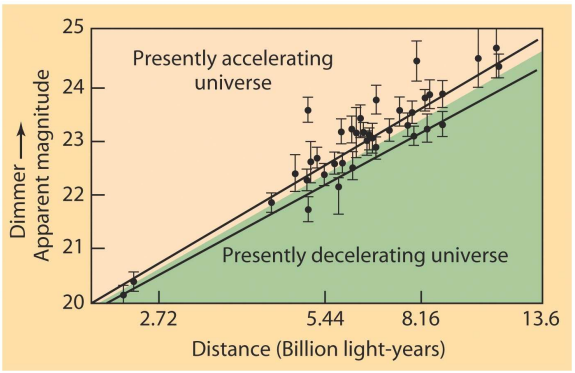


Evidence for Dark Energy

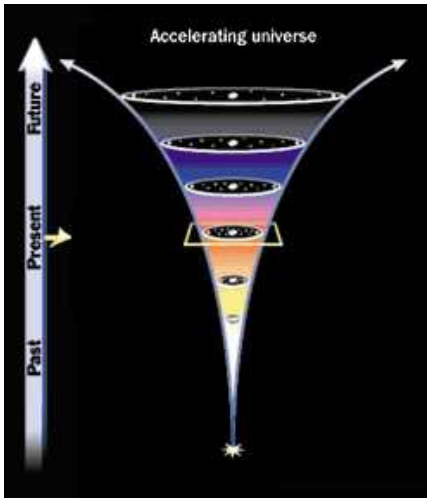
- Distant supernovae are dimmer than they should be if expansion is slowing down

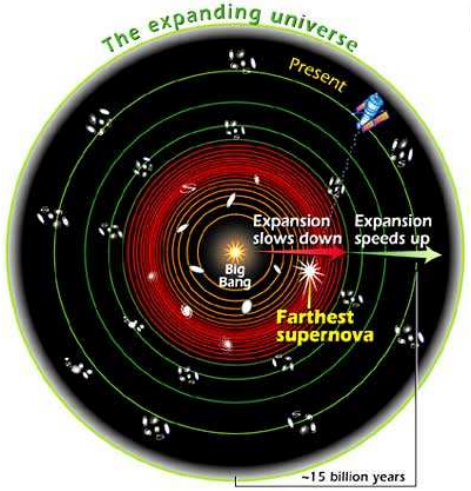


Supernova 1997ff: the most distant supernova ever detected



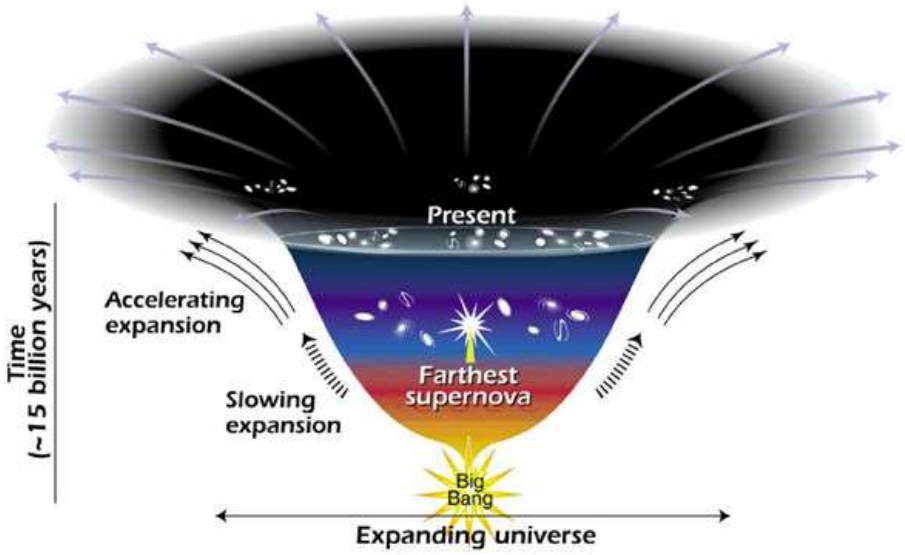
The Accelerating Universe!!!





Whatever this force is, we *think* that it is growing stronger as the universe evolves. The more empty space in the universe, the greater the acceleration – as if the vacuum of space has energy.

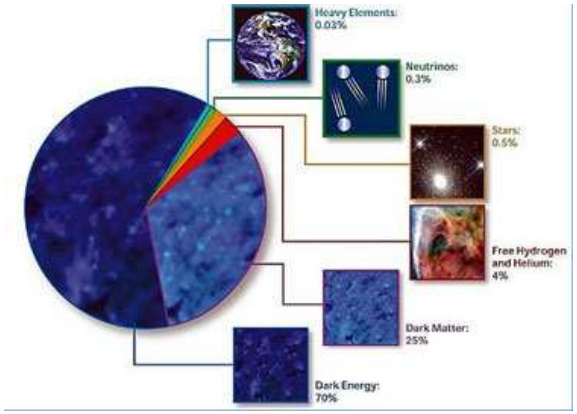
Effects of Dark Energy



http://www.lbl.gov/Publications/Currents/Archive/Apr-06-2001.html

The Accelerating Universe!!!

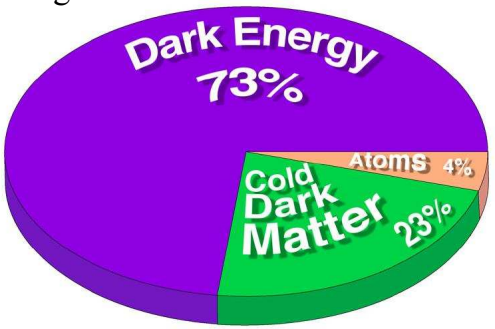
We appear to live in a universe with a flat shape, but which will go on accelerating forever. The universe is 13.7 billion years old, and is now dominated by dark energy. And it will only get worse – the more empty space, the more dark energy.



The Dark Energy even dwarfs dark matter! Regular matter is really insignificant. We *really* don't know anything about what's going on!!

The Distant Future

- Now – the Universe is (nearly) flat
- But the expansion is accelerating
  - An open Universe?
- The future depends on the nature of dark energy

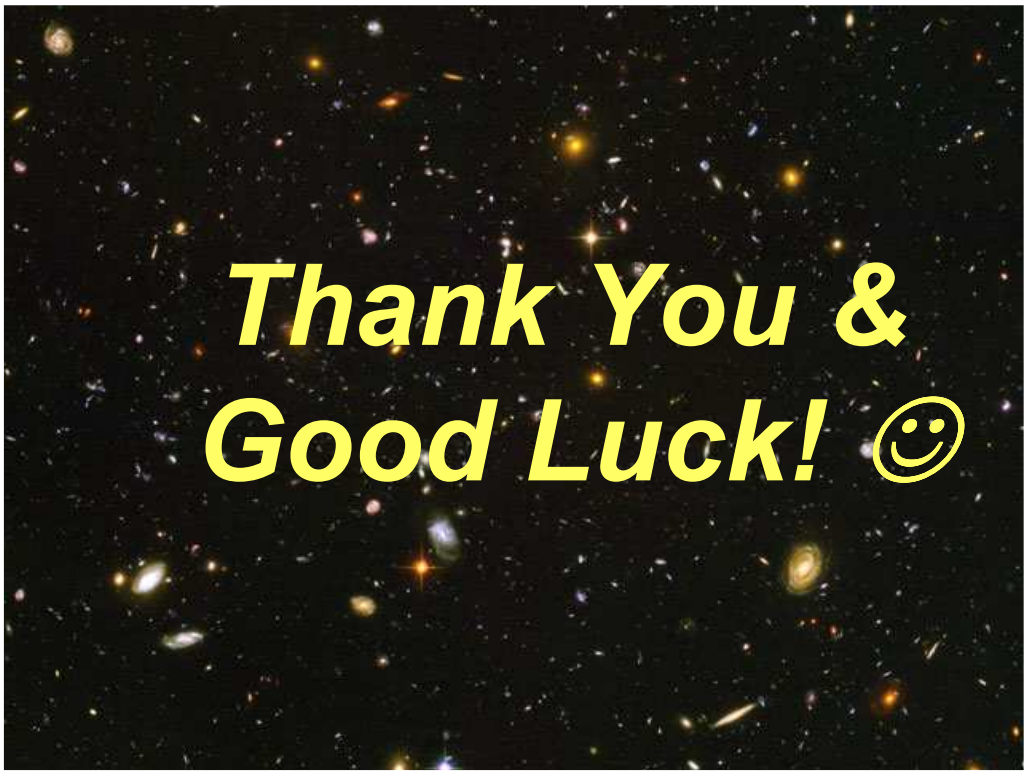


If Dark Energy is Stronger Than We Think?

The Big Rip?

- If repulsive force increases– Brooklyn may expand too.
- Gravity/E&M forces can not hold Galaxies rip apart
- Could rip the MilkyWay apart in ~1 billion years
- Earth gets ripped apart soon after
- You get ripped apart!

Unlikely to be true. We will know shortly.


Thank You &
Good Luck! ☺